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The Recent Pendulum Observations in India.

By Major G. P. Lenox-Conyngham, R.E.

At the beginning of 1904 a new series of pendulum observations for the determination of the force of gravity was begun in India.

The apparatus was of the von Sterneck pattern, and included four half-seconds pendulums. It was made in Vienna, but was fitted in Potsdam with the auxiliaries required for the determination of the effect of the flexure of the stand by Professor Schumann's method.

Five tours have been made with the apparatus since its arrival in India, but it is not my intention to give in detail the results that have been obtained, as they are in course of being brought out in one of the publications of the Survey of India. I merely propose at present to touch on points of special interest, more particularly as they bear on the analysis of the deflections of the plumb-line from the normal to the Earth's surface, which was given by Colonel Burrard in the *Monthly Notices* of January 1902, and subsequently, in greater detail, in Professional Paper No. 5 of the Survey of India.

It may be well to recapitulate shortly the results of that analysis.

Colonel Burrard showed that the deflections revealed by the latitude observations arrange themselves in zones which appear to be parallel to the general trend of the Himalayan Ranges.

There is first, at the foot of the hills, a zone of large northerly deflections, which decrease rapidly as the distance from the hills increases. Secondly, there is a zone of southerly deflections; and thirdly, a second zone of considerable northerly deflection.

Up to the time of the publication of Colonel Burrard's analysis it had been the custom to ascribe the rapid falling off of the attraction of the Himalayas on the plumb-line to "mountain compensation"; that is to say, to the theory that deficiencies of density underlying mountains compensate the apparent excess of mass, so that the amount of matter in the crust of the Earth is the same, or nearly the same, in mountainous regions as elsewhere.

Other anomalies in the directions assumed by the plumb-line were attributed to purely local variations in the density of the surface strata.

Colonel Burrard showed that the theory of compensation was incapable of explaining both the large deflections at the foot of the hills and the rapid falling off that occurs at moderate distances from them; and further, by exhibiting the way in which the deflections can be classified, he made it clear that their causes were not purely local in character.

To account for the observed phenomena, he showed that it is necessary to suppose that the Himalayas are compensated to some extent, and that there exists "an invisible chain of excessive density" running parallel to the Himalayas, right across India

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from the Bay of Bengal to the Punjab. I may mention that all the latitude observations which have been made in those regions since he put forward this idea go to corroborate it.

A general gravimetric survey of India is the object with which the pendulum observations have been begun, but in planning some of the first programmes of observation it was thought desirable to test, as far as was convenient, Colonel Burrard's deduction as to the distribution of mass in the hills and in the plains below them; that is to say, to find out by means of the pendulum whether the force of gravity in the Himalayas is less than it would be if the material composing them were of average density, and to see whether at points situated over the supposed hidden chain of excessive density the force of gravity is correspondingly high.

The mean surface density of the Earth may be taken to be 2·8, and the mean density of the Earth as a whole 5·6, or twice the surface density.

To determine whether the observed force of gravity is in excess or defect of the normal, we must know what is the normal force for the station of observation.

To find the normal force in a given latitude, at sea-level, Helmert's formula has been used, namely:—

$$\gamma_0 = 978{\cdot}00(1 + 0{\cdot}005310 \sin^2 \phi)$$

in centimetres per second per second.

This quantity requires in general three corrections to give the value at the station of observation:

First, the correction on account of the height above sea-level,

$$-\gamma_0 \frac{2h}{R},$$

where h is the height of station above sea-level, and R is the mean radius of the Earth.

Secondly, the correction on account of the attraction of the mass between sea-level and the station. If the station is situated on an extensive level plateau, the material underlying it having a density of 2·8, this correction is

$$+\gamma_0 \frac{3}{4}\frac{h}{R}.$$

If the surroundings of the station do not resemble a level plateau, a correction is required to allow for the difference. This is called the orographical correction; it has to be separately computed for each station, and depends on the topography of the region.

In practice, it is more convenient to apply these corrections to the observed force of gravity g, and to compare this corrected value, called g''_0, with the value of γ_0 given by the formula.

We thus obtain for every station the quantity $(g''_0 - \gamma_0)$. If this is positive it denotes that gravity is in excess of the normal; and if negative, that it is in defect.

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To give a material interpretation to the quantity $(g''_0 - \gamma_0)$ we may suppose that an excess in g is caused by an excess of matter in the form of a horizontal disc of indefinitely great radius underlying the station, when the thickness of the disc will be proportional to the observed excess in g.

The attraction of a disc of infinite radius on any point in its axis is

$$= 2\pi h \delta G,$$

where h is its thickness, δ its density, and G the gravitational constant.

The attraction of the Earth on a point on its surface

$$= \frac{4}{3}\pi R \Delta G,$$

where R is the mean radius and Δ the mean density.

Hence, calling the attraction of the disc A, and that of the Earth g, we have

$$\frac{A}{g} = \frac{3}{2}\,\frac{h}{R}\,\frac{\delta}{\Delta}.$$

Putting $\dfrac{\delta}{\Delta} = \dfrac{1}{2}$, $R = 21000000$ ft., and $g = 978$ cm.

$$A = h \times 0{\cdot}000035,$$

A being expressed in centimetres, and h in feet.

Therefore the thickness of a disc of density 2·8, which will give a value of 0·001 cm. to A is 28·6 feet; in other words, the presence of an excess of matter equivalent to a disc 28·6 feet thick will account for a value of + 0·001 cm. in $(g''_0 - \gamma_0)$.

The first set of observations carried out with a view to testing Colonel Burrard's theory began at the station of Chatra, latitude 24° 13′, longitude 88° 23′, height above sea-level, 64 feet; and, running approximately up the meridian, ended at Sandakphu, latitude 27° 6′, longitude 88° 0′, height above sea-level, 11,766 feet.

The position of the stations, the values of $(g''_0 - \gamma_0)$, and the thicknesses of the discs of excess or defect are given in Table I.

TABLE I.

Station.	Latitude.		Longitude.		Height.	$g''_0 - \gamma_0$.	Thickness of Disc.
	°	′	°	′	feet.	cm.	feet.
Chatra . . .	24	13	88	23	64	+0·009	+ 257
Kisnapur . .	25	2	88	28	113	+0·033	+ 944
Ramchandpur .	25	41	88	33	132	+0·001	+ 29
Kesarbari . .	26	8	88	31	204	−0·043	−1230
Jalpaiguri . .	26	31	88	44	268	−0·096	−2746
Siliguri . .	26	42	88	25	387	−0·137	−3914
Kurseong . .	26	53	88	17	4,913	−0·130	−3718
Darjeeling . .	27	3	88	16	6,966	−0·143	−4090
Sandakphu . .	27	6	88	0	11,766	−0·150	−4286

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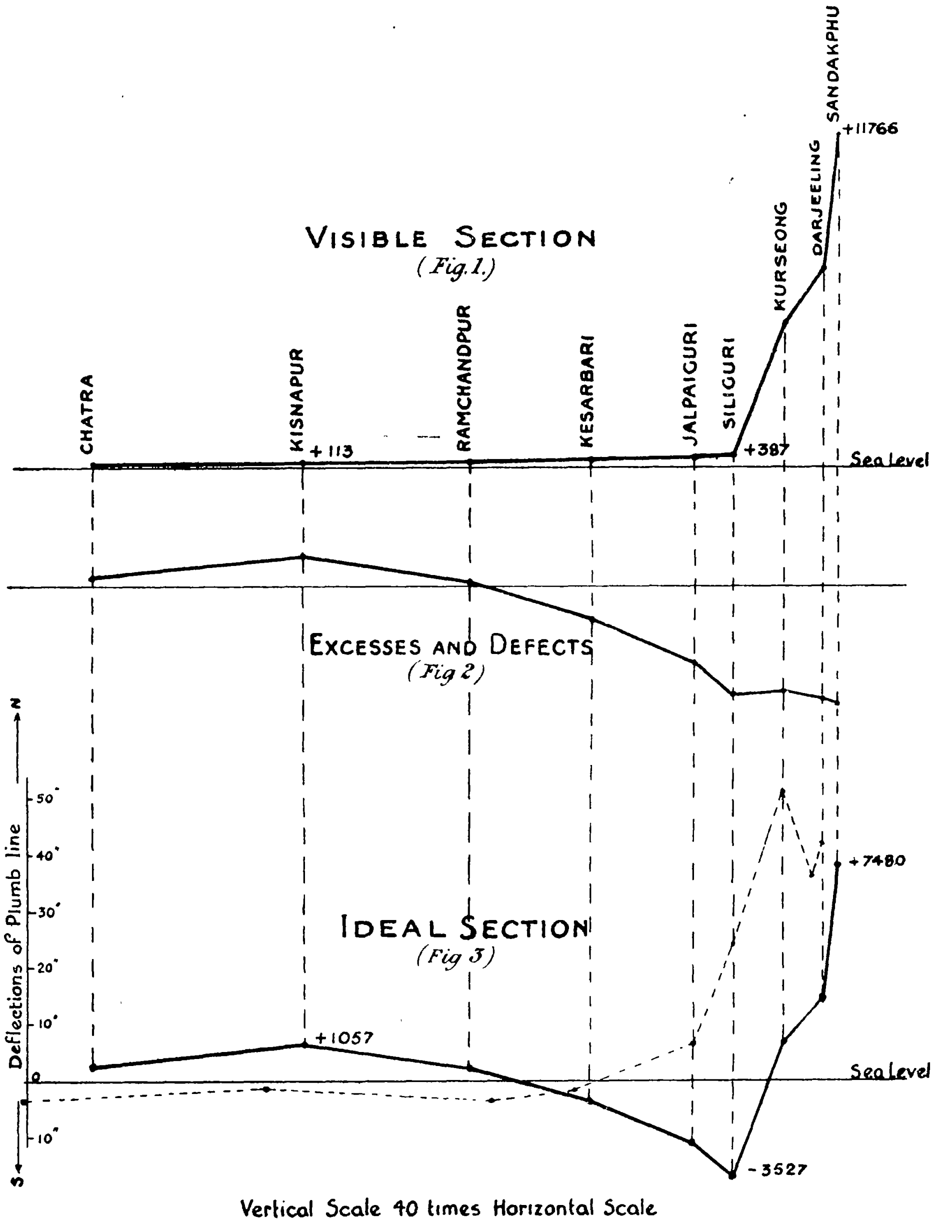
Three diagrams have been drawn to show the meaning of these figures.

Fig. 1 is a section of the country as we see it, but with the vertical scale exaggerated—it is 40 times the horizontal scale. The plain rises very slowly and quite evenly until the foot of the hills is reached at a point just north of Siliguri; thence there is a steep climb all the way to Sandakphu.



In fig. 2 the ordinates represent, on same scale as in fig. 1, the thicknesses of the discs of excess or defect; and in fig. 3 the ordinates are the algebraic sums of those in figs. 1 and 2; this diagram therefore gives an ideal section showing the form the country would

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take if the density were made homogeneous by compression or expansion as the case might be.

Beginning at the northern end, we see that there is a deficiency of density underlying the Himalayas, but that it does not amount to total compensation.

In the case of Sandakphu the height must be reduced by about one-third to give the true efficacy of the hill as an attracting mass. In the other stations the proportion of reduction is higher, for the deficiencies are nearly the same, and the heights less. Under Siliguri, which is in flat ground only 387 feet above sea-level, the deficiency is almost as great as at Sandakphu. So that in the ideal section this station is 3527 feet below sea-level. In other words, if there were no variations of density, there would be a great ditch at the foot of the hills.

Moving south from Siliguri, the deficiency gradually becomes less, and at Ramchandpur, about 80 miles from the hills, it gives place to a small excess; this increases, and attains a maximum at Kisnapur some 50 miles further south.

In fig. 3 the dotted line shows the variations in the deflections of the plumb-line which have been revealed by the latitude observations. When the curve is above the datum the deflections are to the north, and when below it to the south.

It is easy, with this ideal section before one, to see why there should be southerly deflections between Ramchandpur and Kesarbari, for the great dip to the immediate north largely counteracts the effect of the more distant Himalayas while the Kisnapur hill is exerting its full influence.

The very rapid increase in the northerly deflections between Jalpaiguri and Kurseong is also quite intelligible: at Jalpaiguri there are about equal amounts of defect north and south of the station, and the northerly deflection measures the preponderance of the Himalayan attraction over that of the Kisnapur hill: at Siliguri the greater part of the "ditch" is to the south, and the Himalayas more immediately to the north: and at Kurseong the negative attraction of the ditch and the positive one of the Himalayas are acting wholly in concert to produce a northerly deflection of the plumb-line—the greatest that has been observed in India.

An extension both of the latitude and of the pendulum observations to the south of Chatra is to be desired, and it is unfortunate that an attempt to determine g at Calcutta, which was made early in 1904, ended in failure. This failure was not without interest, and I may briefly refer to it.

The whole of Calcutta may almost be said to be floating; there appears to be a crust of very moderate thickness resting on a spongy mass of unknown depth. This crust is not very rigid, and the result is that the traffic of the city sets up vibrations in it.

It had often been noticed that there was great difficulty in making nadir observations in mercury in Calcutta, but it had not occurred to me that these tremors would be of sufficiently long period to

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affect a pendulum: when however the apparatus was set up, it soon appeared that they were well able to do so. A pendulum carefully brought to rest would in 20 seconds be swinging through an arc of 4′ or so; this would rise and fall irregularly, but sometimes—I suppose when the incidence of traffic happened to be favourable—a large amplitude would be attained in a few minutes; I observed an amplitude of 17′, which was attained in less than 10 minutes from the time when the pendulum was brought to rest. The time of vibration of the pendulum was of course quite untrustworthy as a measure of the force of gravity.

It will no doubt be possible to find places quite near Calcutta where these tremors will not be felt, but there were reasons against undertaking this at the time, and so, for the present, we have no determination of *g* south of Chatra, in that region.

One more point of interest belonging to this series of observations may be mentioned, namely, the visit of Dr. Hecker of the Prussian Geodetic Institute. Dr. Hecker had been making some voyages in Eastern waters to determine the force of gravity over the ocean by means of barometers and hypsometers, but he was also equipped with a set of half-seconds pendulums which he had swung at Potsdam before starting. Bringing his pendulums with him, he joined me at Jalpaiguri, and there we made simultaneous sets of swings. After this he returned to Potsdam, and again swung his pendulums, so that he has a good determination of *g* at Jalpaiguri in terms of *g* at Potsdam.

The Indian pendulums were swung at Kew and Greenwich before being taken out to India, so that we have the value of *g* at our base station, Dehra Dûn, in terms of *g* at Kew; Kew was connected with Potsdam in 1900 by Mr. G. R. Putnam; and the Indian operations connect Jalpaiguri with Dehra Dûn. Thus there is a complete circuit.

Dr. Hecker's value of *g* at Jalpaiguri, based on Potsdam direct, is

978·924 cm.

The value of the same quantity obtained through Kew and Dehra Dûn is

978·922 cm.

The agreement is satisfactory, indicating, as it does, that the Indian pendulums have not changed their lengths since they were swung at Kew.

The next series of observations which bears on the question of mountain compensation and the existence of the hidden chain of high density is one that began at Simla, and, crossing the plains of the Punjab and part of Sind, ended at Quetta.

This line includes one of the arcs of longitude which had long been a problem. The arc in question is Amritsar–Multan. At Amritsar the Himalayas are, on a fairly clear day, easily visible to

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the east, while to the west there is nothing but the perfectly flat plains of the Punjab. At Multan the Suleiman Mountains close in the western horizon, and on the eastern side there is no visible source of attraction. Yet the arc of longitude showed that the plumb-lines at these two places are attracted inwards, away from the mountains and towards the level plains; and this was one of the facts utilised by Colonel Burrard to fix the position of the line of excessive density.

The pendulum stations which throw light on this problem are shown in Table II.

TABLE II.

Station.	Latitude.		Longitude.		Height.	$g''_0-\gamma_0$.	Thickness of disc.
	°	′	°	′	feet.	cm.	feet.
Pathankot	32	17	75	39	1088	−0·179	−5114
Mian Mir	31	32	74	23	708	+0·004	+ 114
Montgomery	30	40	73	6	557	+0·003	+ 86
Multan	30	11	71	25	404	−0·045	−1287
Dera Ghazi Khan	30	4	70	46	397	−0·088	−2517

We have as yet no station in the Himalayas near Pathankot, nor any in the Suleiman Mountains; but since observations at Mussooree and Simla in the Himalayas and at Quetta in the Baluchistan Highlands all show defects in gravity similar to those found at Darjeeling and Sandakphu, we may surmise with fair certainty that the conditions will be found the same in the hills east of Pathankot and west of Dera Ghazi Khan.

This assumption has been made in drawing the diagrams of the excesses and defects and the ideal section on this line.

Two noteworthy points in the ideal section are (1) the great deficiency in g at Pathankot, and consequently the great depth of the "ditch" at the foot of the Himalayas; and (2) the occurrence of a similar depression or "ditch" at Dera Ghazi Khan, which lies at the foot of the Suleiman Mountains.

In the case of the mountains of Northern India, this defect of gravity at the foot is now a fairly well-established feature, for it has been found at several other places at the foot of the Himalayas, namely, at some six stations in and near Dehra Dûn, and at Kalka, the point where the road to Simla leaves the plains; and it occurs again at Sibi, at the foot of the Baluchistan hills, among which Quetta lies.

It will be of interest to see whether the case is the same in the mountains of Southern and Central India, which are of quite different geological formation.

Some observations have been made in the Nilgiris, the Shevaroys, and the Pulnai hills, and some are in course of being made in the Vindhya ranges, but the results are not yet available.

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The rise in density as we recede from the Himalayas is well shown by a series of observations on the northern part of Everest's Great Arc of Meridian. The particulars are given in Table III.

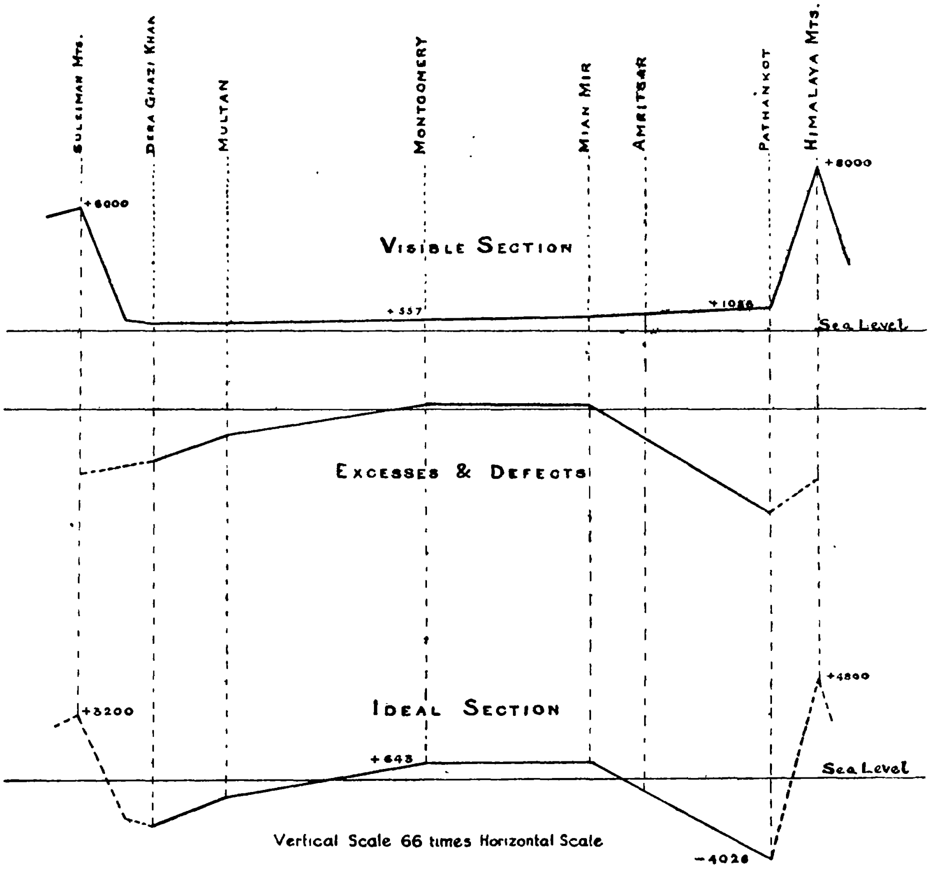

FIG. 2.

TABLE III.

Station.	Latitude.		Longitude.		Height.	$g''_0 - \gamma_0$.	Thickness of Disc.
	°	′	°	′	feet.	cm.	feet.
Mussooree .	30	27	78	3	7129	−0·115	−3289
Rajpur .	30	24	78	6	3321	−0·124	−3546
Dehra Dûn .	30	19	78	3	2239	−0·126	−3600
Asarori .	30	14	77	58	2467	−0·112	−3203
Mohan .	30	11	77	55	1660	−0·104	−2974
Nojli .	29	53	77	40	879	−0·095	−2717
Kaliana .	29	31	77	39	810	−0·058	−1659
Meerut .	29	0	77	42	734	−0·027	−772
Gesupur .	28	33	77	42	691	−0·020	−572

These stations are closer together than those of the other series that have been spoken of, and we are consequently able to form a

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more precise idea of the way in which the deficiency in g diminishes as we recede from the hills.

The diagrams which follow correspond to those which illustrate the other lines of observation.

The station called Asarori is near the summit of the Siwalik range, and Mohan in the plains at its southern edge. There does not appear to be any "ditch" at the base of the Siwaliks corresponding to that which runs along the foot of the Himalayas. The deficiency at Mohan is rather less than we should have expected if we had only had the results at Dehra Dûn and Nojli to judge by. It looks, in fact, as if in the uplifting of the Siwaliks some compression of the crust had taken place, causing a local increase of density, not indeed enough to make good the great deficiency of the sub-Himalayan belt, but sufficient to impress a distinct mark on the curve of defects.

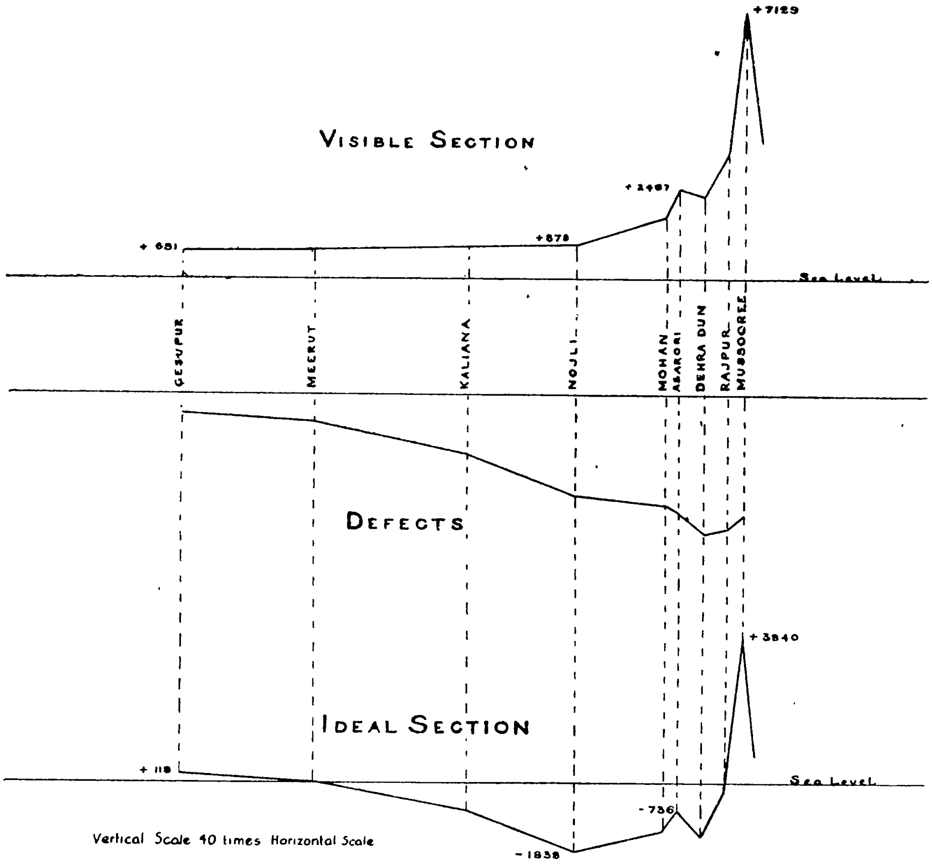

Fig. 3.

The quantity $(g''_0 - \gamma_0)$ has its greatest negative value at Dehra Dûn, but in the ideal section Nojli is at the deepest point of the "ditch," as there is at that station only a small surplus of visible matter to set against the defect due to want of density.

From Nojli the deficiency in g''_0 diminishes very steadily;

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at Gesupur, about 100 miles south of Dehra Dûn, it amounts to 0·020; and if the diminution continues at the same rate $(g''_0 - \gamma_0)$, will change sign at about 150 miles from that place.

The pendulum observations do not as yet go far enough to give any evidence as to the maximum value which $(g''_0 - \gamma_0)$ will attain, nor as to the position of the crest of the invisible chain of high density.

This is the only line on which the stations are sufficiently near together to give a definite idea of the form of any part of the hidden chain, and more stations, not too far apart—say at intervals of about 20 miles—are urgently required to determine the position and height of the crest, and to reveal the section of the southern slopes.

The general conclusion to be derived from the pendulum observations, as far as they have yet gone, confirms Colonel Burrard's theory of the distribution of mass in the Himalayas and the plains below them. The mountains are compensated to some extent, but by no means wholly; and there does exist a belt of high density running parallel to the Himalayas, and some 200 or 300 miles from them. The effects, however, which Colonel Burrard attributed to the "hidden chain" must, it now appears, be ascribed only in part to that cause and in part to the deep "ditch" which lies between the hidden chain and the foot of the hills.

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A proposal for the Comparison of the Stellar Magnitude Scales of the different Observatories taking part in the Astrographic Catalogue. By H. H. Turner, D.Sc., F.R.S., Savilian Professor.

1. One of the questions on the programme for the forthcoming meeting of the Comité Permanent for the Astrographic Catalogue (summoned for April 18–24 in Paris) is that of the best method for coordinating the measures of stellar magnitude. The different observatories have adopted different procedures, and the task of forming a homogeneous system is not by any means easy.

By the arrangement of the work, there is a zone 1° in breadth common to each pair of observatories at the separating belts; and hence there is material for a comparison of the two scales; but this implies the identification of images of the same star, which in itself involves a good deal of labour.

2. The proposal I wish to advocate is of a very simple character, and at the same time it will probably provide a sufficiently good comparison of the scales, with comparatively little labour. It is—*That the number of images recorded under each unit of the magnitude scale be counted and tabulated.*